The next generation of coherent x-ray science at APS

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The advent of third-generation storage rings have ushered in dramatically new capabilities for studying the structure of matter with coherent x-ray beams. Scanning x-ray microscopes that utilize a diffraction-limited focus and techniques utilizing coherent scattering such as x-ray photon correlation spectroscopy (XPCS), x-ray speckle, x-ray holography, and x-ray coherent diffraction imaging (CDI), require spatially and temporally coherent illumination. Because the flux per coherent mode scales linearly with the brilliance of the source and as the inverse-third power of the photon energy, these experiments, especially hard x-ray experiments, have a tremendous appetite for source brilliance. The high brilliance of undulator sources at APS and elsewhere has led to rapid growth of fundamental demonstrations and practical applications alike. However, this "first generation of coherent x-ray science", now enterering its second decade, is running into hard limits imposed by the stability and coherent flux of the x-ray beams delivered to the experiments. In parallel, the limited dynamic range and slow readout rate of detectors typically used for these experiments - CCD cameras - is a major obstacle to progress for many applications. Third, until very recently, the methods used for phase retrieval in CDI experiments were prone to artifact and suffered limited applicability to many real-world samples.

The next five years will see the emergence of a second generation in coherent x-ray science. The coherent flux will be increased by use of extended straight sections containing long undulators and used more efficiently by matching the source phase space to the experiments through use of optimized beta functions and beamline optics. Beam stability will be increased to the nanoradian level over hour-long periods by use of better mirror and monochromator designs. Use of focusing optics to tailor the coherent x-ray beam to the sample and introduce wavefront curvature, advanced analysis algorithms, and scanning methods for study of extended samples with unambiguous phase retrieval will become commonplace. Many experiments will take advantage of high speed megapixel array detectors with single-photon sensitivity, zero noise, and a dynamic range of greater than 10^6. The tremendous data valume and rates using these detectors will be supported by ancillary developments in broadband data storage, transport, and multiprocessor analysis.

Beamline 8-ID currently excels at XPCS. After upgrading, 8-ID will employ vertically focusing optics, a long straight section, and magahertz-readout array detectors. These improvements will extend the range of sample dynamics that can be probed via XPCS at 8-ID to time scales extending from the slowest neutron spin echo (NSE) measurements ($\sim 10^{-6}$ s) to near static ($\sim 10^{3}$ s) conditions. Improved flow cells, microfluidic-mixing cells, and vibrationally-quiet cryostats and furnaces will enable dynamical studies of for radiation-sensitive soft matter, non-equilibrium measurements, and matter at extreme conditions.

Beamline stations 2-ID-B, 8-ID-I, 26-ID-C, 34-ID-C are currently used part-time for CDI. Although groundbreaking advances are being made at these stations, a full-time beamline optimized for CDI would enable more rapid progress and better user access. The new Advanced X-ray Imaging (AXI) beamline, proposed in conjunction with the Argonne Imaging Institute, will be dedicated to nanoscale coherent diffraction imaging in the 2-12 keV energy range. AXI will offer unprecented imaging of micron-scale specimens at 10 nm resolution and beyond with sufficient working distance using a long (~200 m) beamline to accommodate in-situ sample environments including extreme temperatures, magnetic fields, and laser excitation. These capabilities will open the door to nanoscale study of buried structure in materials such as nanoporous metallic foams, ordering and domain transport in the complex oxides, and the internal architecture of cellular organelles such as cytoskeletal actin and nuclear bodies.

Together, improvements in the sources, beamlines, detectors, and sample environments at APS will lead to a new generation of coherent x-ray experiments over the next fiuve years with far broader application to the condensed matter, materials, and life sciences than the previous decade.